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Challenges of information and communication technology in energy efficient smart homes★

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ABSTRACT

Energy saving is an important issue in the [illegible] increasing energy prices. Products and services provided by the information and communication technology (ICT) can support energy efficiency and emissions reductions. The synergy of ICT and a residential [illegible] gives rise to the smart home environment. Ecological and smart home network [illegible]tions should [illegible]ly improve the peoples life satisfaction in the domain of health care, security protection, and efficient management of energy and resource consumption, but they should also ensure personal happy life through easy communication with community people, high level entertainment, continuous education and so on. A smart home in the smart grid is the latest addition to a family of ideas emerging in relation to the ICT usage in the home. This paper presents an overview of the smart home concept and some challenges that ICT faces in that environment.

Contents

1. Introduction

Main resources in [illegible] household are electricity, water, natural gas, and [illegible] oil. Saving a small portion of each in the residential space would have a significant impact on reducing costs, energy consumption and impact on the environment.

Domestic energy use is commonly invisible to the user. People have only a vague idea of how much energy they are using for different purposes and what sort of difference they could make by changing day-to-day behavior or investing in efficiency measures. Key issues are for instance the lack of real time information around consumption and the influence of energy use information on energy-saving behavior. Hence the importance of energy feedback lies mainly in making energy more visible and more amenable to understand and control.

The idea of a smart home seems like something from Hollywood. Indeed, a 1999 movie Smart House presents the comical antics of an American family that wins a "house of the future", complete with an android maid who wreaks havoc. Other films show a science fiction vision of smart home technology that, for the most part, seems rather improbable. However, smart home technology is real and is becoming increasingly sophisticated.

Today our homes already contain many kinds of electronic devices that we use every day, usually without even noticing that there is a computer or an electronic system inside it performing measurements, calculations and adjustments. Thus ordinary

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everyday objects have great potential that is currently just beginning to emerge. As these (often computer-based) powerful information and communications technology (ICT) systems penetrate our lives, their effective and dependable configuration and integration becomes more challenging.

The smart home of the future will be able to collaborate with numerous external entities, let it be alternative energy resources, marketplaces, enterprises, energy providers, etc. The de facto standard for high-level communication today is via (web) services, which allows for flexible functionality integration without revealing details for the implementation. Therefore the heterogeneity is hidden, while a common service based interaction is empowering the creation of sophisticated applications.

The remainder of this paper is organized as follows. Section 2 introduces the relevant terminology and Section 3 presents a system view of the smart home. Section 4 details the design and developmental issues of the ICT in building smart homes. Finally, Section 5 summarizes future trends of the ICT in the smart home environment.

2. Terminology

The smart home concept is a melting pot of different technological trends because a variety of engineering platforms and ICT design paradigms are currently used in the development of smart homes. Moreover, the concept itself is relatively new, hence the relevant terminology is not yet settled down. This section tries to rectify this and thus specifies understood meaning of the most common terms used in the context of smart home.

Actuators are output devices that respond to processed information by altering the environment via electronic or mechanical means. For example, air temperature control is often done with actuators. However the term can also refer to devices which deliver information, rather than altering the environment physically.

Agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. Increasingly, however, applications require multiple agents that can work together.

Ambient intelligence is a multidisciplinary area that embraces a variety of computer science and engineering fields. Of the several computing fields, the first one is ubiquitous or pervasive computing whose major contribution is the development of various ad hoc networking capabilities that exploit highly portable and numerous, very-low-cost computing devices. The second key area is intelligent systems research, which provides learning algorithms and pattern matchers, speech recognition and language translators, and gesture classification and situation assessment. A third element is context awareness; research on this problem lets us track and position objects of all types and represent objects' interactions with their environments. Finally, an appreciation of the social interactions of objects in environments is essential.

Appliance is a piece of equipment (tool or device) designed for a particular practical use or function.

Artificial intelligence (AI) is a subfield of computer science concerned with the concepts and methods of symbolic inference by computer and symbolic knowledge representation for use in making inferences. From the perspective of intelligence, AI can be seen as an attempt to model aspects of human thought on computers. From a research perspective, AI is the study "of how to make computers do things which, at the moment, people do better" [1].

Artificial Neural Network (ANN) is an attempt to simulate the brain. The neural network theory revolves around the idea that certain key properties of biological neurons can be extracted and applied to simulations, thus creating a simulated (and very much simplified) brain. The first important thing to understand then is that the components of an artificial neural network are an attempt to recreate the computing potential of the brain. The second important thing to understand, however, is that no one has ever claimed to simulate anything as complex as an actual brain.**Building Information Model (BIM)** is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward.**Case-Based Reasoning (CBR)** is the act of using old experiences to understand and solve new problems. CBR favors learning from experience, since it is usually easier to learn by retaining a concrete problem solving experience than to generalize from it.

Communication technology includes the principle data transmission and network technologies, i.e. wired & mobile telephony, radio broadcast, wired & wireless data transmission.

Connectivity is, in the most general sense, the ability to connect systems or application programs. Ideally, these connections are established without requiring many changes to the applications or the systems on which they run. For example, device can use multiple networks to connect to the Internet or other devices, and can seamlessly change over to another network if the previous network becomes unavailable or a more suitable network becomes available. Gateways and converter modules can be used to connect an incompatible device to another network type, but ultimately it is applications and their interoperability that determine how compatible systems are connected with each other.

Context aware systems are systems that can adapt their behavior according to the context of their use. Such systems are a component of a ubiquitous computing or pervasive computing environment. Three important aspects of context are: (1) where you are; (2) who you are with; and (3) what resources are nearby.

Data mining is the process of analyzing data from different perspectives and summarizing it into useful information.

Equipment refers to not only the "end-user-devices" (computers & peripherals, digital data recorder-storage-player devices, modems, phones and multimedia mobiles, fax machines, set-top boxes and TV & peripherals), but as well to the "infrastructure" that consist of both hardware and software elements (server and data centers, wired core telecom networks, cellular phone networks, Wireless Local Area Networks, Radio/TV broadcast equipment and micro systems).

Future Internet (FI) is holistic communication and information exchange ecosystem, which will interface, interconnect, integrate and expand today's Internet, public and private intranets and networks of any type and scale, in order to efficiently, transparently, interactively, flexibly, timely, and securely provide services (including essential and critical services) to humans and systems, while still allowing for tussles among the various stakeholders without restricting considerably their choices.

Human-Computer Interaction (HCI) is the study of how people interact with computers and to what extent computers are or are not developed for successful interaction with human beings. One important HCI factor is that different users form different conceptions or mental models about their interactions and have different ways of learning and keeping knowledge and skills (different "cognitive styles" as in, for example, "left-brained" and "right-brained" people). In addition, cultural and national differences play a part.

Information technology encompasses all aspects of computer-related systems, be it the computer hardware, software, data, programming, multimedia, networks, and so on. Information technology is now a global industry, a college degree, a field of study, a professional occupation, and used on a daily basis by millions of people.

Internet of Energy (IoE) is a dynamic network infrastructure that interconnects the energy network with the Internet allowing units of energy (locally generated, stored, and forwarded) to be dispatched when and where it is needed. The related information/data will follow the energy flows thus implementing the necessary information exchange together with the energy transfer.

Internet of Media (IoM) is a network infrastructure that addresses the challenges in scalable video coding and 3D video processing, dynamically adapted to the network conditions. The IoM will give rise to innovative applications such as massive multiplayer mobile games and digital cinema, and in virtual worlds it will place new types of traffic demands on mobile network architectures.

Internet of People (IoP) is a network infrastructure that interconnects growing population of users while promoting their continuous empowerment, preserving their control over their online activities and sustaining free exchanges of ideas. The IoP also provides means to facilitate everyday life of people, communities, organizations, allowing at the same time the creation of any type of business and breaking the barriers between information producer and information consumer.

Internet of Services (IoS) is a software based component that is delivered via different networks and Internet. Research on SOA, Web/enterprise 3.0/X.0, enterprise interoperability, service Web, grid services and semantic Web will address important bits of the IoS puzzle, while improving cooperation between service providers and consumers.

Internet of Things (IoT) is an integrated part of Future Internet including existing and evolving Internet and network developments. It could be conceptually defined as a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network.

Knowledge Base (KB) is a centralized repository for information: a public library, a database of related information about a particular subject. It is not a static collection of information, but a dynamic resource that may itself have the capacity to learn, as part of an artificial intelligence (AI) expert system, for example.

Multi-Agent System (MAS) is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver

Pervasive computing is the increasing integration of the ICT into people's lives and environments, made possible by the growing availability of microprocessors with built-in communications facilities. Pervasive computing involves three converging areas of the ICT: computing ("devices"), communications ("connectivity") and "user interfaces".

Processors are electronic computer components that interpret and analyze input.

Seamless computing is a concept that implies that computers and networks work together without difficulty and can offer users the optimum service anywhere and anytime.

Sensors are input devices that detect environmental changes, user behaviors, human commands, etc.

Services are the final product of ICT including the respective hardware, software, and individual media contents. The ICT services provided through the utilization of computers and networks form the basis for dematerialization of processes and objects. ICT services can be defined as computer based (data and media-processing, computer-aided design (CAD) and computer simulations), telecom-based (tele-working, shopping & conferencing), internet-based (e-business, ecommerce, e-government and e-learning), and GPS-based (navigation, traffic control, security and rescue systems).**Service-Oriented Architecture** (**SOA**) is the underlying structure supporting communications between services.

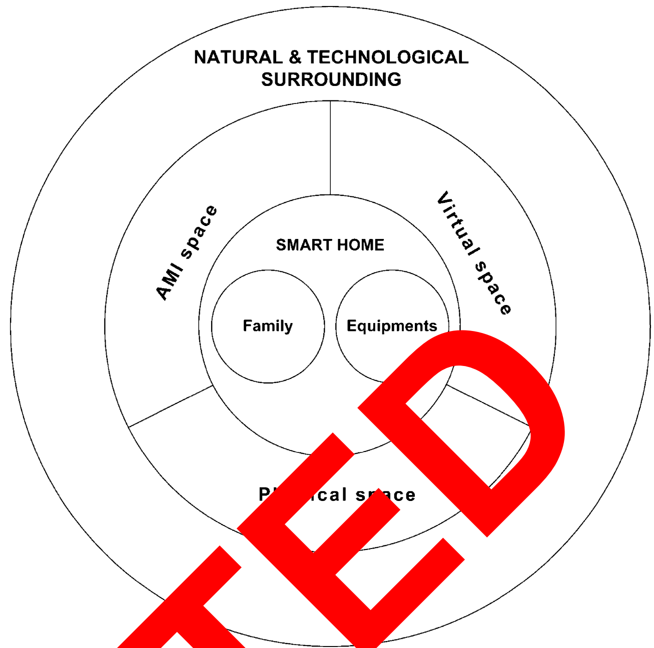

Fig. 1. The smart home environment.

Smart grid is a type of electrical grid which attempts to predict and intelligently respond to the behavior and actions of all electric power users connected to it (suppliers, consumers and those that do both) in order to efficiently deliver reliable, economic, and sustainable electricity services. Refers to the application of digital technology to the electric power sector to improve reliability, reduce cost, increase efficiency, and enable new components and applications.

Smart home is a residence that has appliances, lighting, heating, air conditioning, TVs, computers, entertainment audio & video systems, security, and camera systems that are capable of communicating with one another and can be controlled remotely by a time schedule, from any room in the home, as well as remotely from any location in the world by phone or internet.

Smart meters are innovative and advanced utility meter that record a business or consumers energy, water or gas usage in real time and in greater detail than current conventional meters.

Smart objects are objects that are designed to tailor their responses to their virtual environment, providing a "sense-and-control loop" that works to optimize resources, productivity, and quality.

User interfaces represent the point of contact between the ICT and human users.

Web services are small units of code designed to handle a limited set of tasks. They use the standard web protocols HTTP, XML, SOAP, WSDL, and UDDI

3. Smart home – a system view

A smart home is best viewed as a system with interaction with its surrounding. A system in general is a collection of functional components performing in interaction to achieve an objective or to perform a task within defined boundaries. Every system is interfaced with its surrounding environment, and in this paper the term environment refers to a natural and technological surrounding of a smart home (Fig. 1).

In order to establish the technology requirements that are needed for a smart home, a boundary that defines what a smart

home is must first be established. For the purposes of this paper, a smart home shall be identified as an environment (be it a house, apartment, or living space) where specific appliances within the environment become networked smart objects due to integrated processors and sensors. These appliances typically affect classic building services (heating, ventilation, cooling, safety, and lighting) as well as information, communication, and entertainment devices (PC, phone, TV, etc.). This definition can also be extended to include a wider ranging vision where conventional devices such as furnishings, medicine cabinets, mirrors, windows, doors and carpets can also be made smart and incorporated as functional pieces of a smart home environment.

System is always in dynamic interaction with its surrounding, determined by a constant flow of resources into the systems, and flow of system outputs, intended and incidental, out into the environment.

The primary function of the smart home is to adapt automatically to the needs of the residents and how they go about their daily routines. The system would be used to provide the resident with greater convenience and safety, and result in energy conservation. Additionally, western world is seeing an increasingly ageing population, and such pervasive environments are seeing growing interest due to the need to enable elder care and by extension provide care for disabled individuals.

The most common concept of space in current dwellings is its categorization by functions, such as sleeping rooms, bathroom and living room [2] that can be traced to the "form follows function" design philosophy by American architect Louis Sullivan's established more than a century ago. But due to the changes in people's preferences and needs, the concept of space for houses in the near future might have to be reconsidered. In the future, people will execute an increasing amount of their everyday activities in or around the dwelling. The border between homework and professional work will loosen up [3]. A greater number of activities will also be supported by different kinds of Ambient Intelligence. Space in the information society is becoming more complex and can be understood as three spaces integrated into a new concept of home environment where Virtual Space (VS) and Ambient Intelligent Space (AmI-S) is combined with Physical Space (PS) [4].

The smart home environment is highly characterized by heterogeneity with many systems that need interoperate to perform their tasks efficiently. With rapid growth of services, applications and devices in smart home environment, the interoperability factor seems still elusive. This is due to the nature of smart home as distributed architecture that needs certain degree of interoperability and interoperation for managing heterogeneous systems comprising of different platforms.

These heterogeneous systems are developed in isolation and consist of different operating systems, different programming platform and different layer of services. There is need for a mechanism that could make heterogeneous systems "talk" to each other and interoperate in an efficient manner regardless of operating platform. Context awareness is emphasized in order to provide automatic services in a smart home, but it is used more generally to include nearby people, devices, lighting, noise level, network availability, and even the social situation; e.g., whether you are with your family or a friend from school.

If the home system wants to dynamically adapt its behaviors according to the user's activities and environments, awareness of the user's and device-related activities and environment are required.

3.1. *Identification, data collection and communication*

Research in Ambient Intelligence (AmI) focuses specifically on users and on how they relate to the surrounding environment; namely AmI systems attempt to sense the users' state, anticipate their needs and adapt the environment to their preferences [5]. Such systems usually rely on specific hardware in order to gather information about the environment state; such data may for instance be collected via pervasively deployed wireless sensor nodes, i.e. small devices equipped with sensors, a processor and a transceiver unit.

Such collected data might be profitably used to identify and profile user habits. In this context, data mining techniques allow for an intelligent analysis of environmental data in order to detect behavior patterns and classify them into profiles. Careful processing of sensory data may be used to infer descriptive models showing the relationships of interest between environmental variables and the user, while predictive models may prove reliable inference on future behavior of users population in the considered environment.

User profiling applications in AmI have targeted environment personalization as for instance in [6], where a reinforcement learning algorithm is used to learn preferred music and lighting settings, adaptable to preference changes. User profiling can also be used to detect significant changes in resident's behavior preserving their safety. Other applications regard personalization of building energy and comfort management systems [7]. Data collected by wireless sensor are used to create profiles of the inhabitants, and a prediction algorithm allows the automatic setting of system parameters in order to optimize energy consumption.

It is necessary to have appliances energy consumption profiles in order to identify in real time the abnormal situations where appliance's energy consumption behavior is not compatible with its known energy consumption profile patterns.

Some systems use the dependency relationships that exist between various energy consumption activities. Such dependency relationships are used to provide intelligent and proactive advice/suggestion on the effect of energy consumption activities on its related activities [8].

There are some internal relationships that exist between internal environment and appliances, for example relationship between fridge energy consumption and ambient temperature and also between fridge energy consumption and cooking activity if fridge and cooker are in same kitchen.

The dependencies between appliances and internal home environments are internal dependencies and the dependencies that exist between appliances and external environment are known as external dependencies. Such dependencies include relationship between weather conditions and activities of appliances such as heating appliances activities and washing activities, etc.

The context sensitivity information enabled by such dependency relationships allows the system to take various relationships into account that may exist between energy consumption activities and provide intelligent advice to household.

The amount of the data generated by the sensors is growing rapidly. To extract meaningful information from the database is a very resource-consuming task. In order to reduce response time and satisfy the users' queries, the raw data need to be preprocessed and analyzed, so the system needs to convert these data into meaningful information and store them in a collection of analytic databases.

The analytic data can be aggregated into high or abstract level information about energy usage such as type of appliances, region of households, period of time and etc. The information can be drilled down to high resolution energy usage data.

The basic function of the users and appliances profiles is the characterization of users' behavior so that some settings of the energy management system can be made automatically.

Most energy usage of buildings throughout their life cycle is during the operational stage. The decisions made in the conception and design stages of new buildings, as well as in renovation stages

of existing buildings, influence about 80% of the total life cycle energy consumption. Thermal properties of a building are generally unknown to the occupant of a residential home. Information already collected in the architecture, engineering and construction industry is often not considered and is neglected as soon as the project is finished. Reusing this knowledge to optimize energy consumption seems natural, as nowadays the information is often already available in a structured form as building information model (BIM). The more knowledge is available about building properties of the smart home, the better the system can act as an autonomous caretaker in order to create an environmental-friendly and comfortable ambience. Therefore, the transformation of information from a building information model to a more intelligent knowledge base is necessary as foundation of a sophisticated system [9].

In existing electricity infrastructure we are witnessing a typical centralized approach where few powerful central stations broadcast energy to the different consumers. However in order to tackle the ever rising need for energy and comply with social and economic demands of our times, we must move towards increasing the usage of alternative energy resources which are smaller and decentralized. This leads to a very dynamic future energy network, where electricity will be produced in a distributed way, where customers will be not only consumers but also producers (hence they are called *prosumers*), and where bidirectional interaction between producers, consumers and other entities will be possible [10].

The emerging Internet of Energy [11], and more specifically its core entity i.e. the smart grid, is a highly dynamic complex ecosystem of energy production and consumption parties that heavily uses ICT in order to be more efficient compared to its current traditional operation. Additionally the smart grid enables the creation of new innovative services based on bidirectional interaction of its stakeholders.

Due to developments in the embedded systems, the energy consuming/producing devices will be no more considered as black-boxes but will also get interconnected, which will provide fine-grained information, e.g. energy optimization per device. It is also expected that they will provide their functionality as services and be able to consume on-line services (Internet of Services).

4. ICT issues in the smart home environment

The vision of Future Internet is based on the merging of computer networks, Internet of Things (IoT), Internet of People (IoP), Internet of Energy (IoE), Internet of Media (IoM), and Internet of Services (IoS), into a common global IT platform of seamless networks and networked “smart things/objects”.

The Internet of Things could allow people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service. This is stated as well in the ITU vision of the IoT, according to which: “From anytime, anyplace connectivity for anyone, we will now have connectivity for anything” [12].

4.1. Technological and social issues

In the IoT, “smart things/objects” are expected to become active participants in business, information and social processes where they are enabled to interact and communicate among them-selves and with the environment by exchanging data and information “sensed” about the environment, while reacting autonomously to the “real/physical world” events and influencing it by running processes that trigger actions and create services with or without direct human intervention.

Services will be able to interact with these “smart things/objects” using standard interfaces that will provide the necessary link via the Internet, to query and change their state and retrieve any information associated with them, taking into account security and privacy issues.

The vision of what exactly the Internet of Things will be, and what will be its final architecture, is still diverging. Some of the issues involved are given below.

The space in which a smart environment is set up naturally plays an important role in the design process. In the case of a home a major obstacle is the way in which people regard their homes; the home is usually considered a very personal environment, almost sacred, where any intrusion or modification may be considered unacceptable.

Normally newly-built homes contain little or no smart home technology at all, even if installation would simply be incorporate during construction of the building. During the design phase it would be relatively easy to make changes to the infrastructure, home networks and electricity but the customer is rarely consulted at this stage. The later changes are made, the more they will cost to implement [13], and typically they happen after the customer has already moved in.

Problems arise when new devices and networks are installed in old buildings that lack any infrastructural support. Adding new wiring or making changes to the electrical network however can be very challenging and expensive.

The challenges for the smart home as a platform for compatibility and integration of fundamental components involve the diversity of the networked devices and the robustness of the system as a whole. Heterogeneity of devices, compatibility and security are crucial issues in the process. Privacy and security are also important issues since devices can access private or otherwise delicate information regarding users and their surroundings. A smart home can collect large amounts of data related to user's activities, personal preferences and personal data that could be misused to endanger the privacy of the occupants. It is also important to note that wireless networks can also be accessed from outside the home and that mobile devices can be exposed to unsecured foreign networks where they might be compromised.

The requirements for a smart home network are rather demanding; it has to be reconfigurable, self-organizing, dependable, secure, and consume minimal energy. New algorithms for inter-device collaboration and communication are needed and the coordination between the artificial intelligence and reasoning software is also difficult to implement. The smart home platform should be easily scalable and it should be able to move tasks inside itself and perform load balancing of the network. Resource management, for example locating all temperature sensors inside a room and gathering their measurements, is a very important feature, especially for more critical services, such as alarms and environmental controls. Load balancing and fault tolerance become important when there are power outages, malfunctions or network problems or part of the network is not accessible.

Compatibility is another major obstacle to the seamless integration of devices and networks. Even with adapters and converters some functionality might be lost or altered, possibly leading to other problems. There might never be a universal general smart home protocol for all devices and this must be considered when smart homes are being implemented. In practice this means that a smart home system has to be able to support a large variety of standards and there also has to be room for future expansion.

Software for the smart home has to be written differently to current standalone applications. Smart home software architecture is comprised of multiple embedded software components that interact with each other and the amount of different modules, agents and databases can be large. Writing software that is open to new

components and that adapts to new situations and anticipates behavior will be the main challenge for the future.

Users of different ages and from different demographics have different abilities, desires and needs, and these must all be considered in the smart home design process. However many products today are not customizable to the needs of individual users, being designed for the average user and the mass market.

People's attitudes also differ with regard to technology adoption. Some, such as early adopters, appreciate having the latest technology in their homes while others fear or mistrust anything new and unfamiliar.

4.2. Paradox of technology

The complexity of the technological component in a smart home is directly proportional to the complexity of the expected scenarios. Functionality can be as simple as turning lights off and on using a remote control panel, or may be as complex as determining what mood an inhabitant is currently in and choosing the appropriate theme of light and music accordingly.

These emerging technologies are often claimed to make our life easier and our interaction with devices and commodities more intuitive. To some extent, this might be a valid claim. But when the number of smart devices starts to grow gigantically, users are often overwhelmed with the many things they need to learn and operate. The spacious variety of devices and functionalities needed in a smart environment makes it difficult to integrate all controlling terminals together into a single terminal. Especially given that these devices are often provided by different manufacturers. This imposes a requirement to have at least one controlling unit for each set of logically or physically connected devices making interaction more complex and cognitively demanding.

User wants the interface to know what he wants, and to learn about him. But he also wants it to do this in a way that does not bother him by making poor assumptions, and that is probably one of the biggest challenges.

Artificial Neural Networks (ANNs) can be used to do things such as facial and optical character recognition. In [illegible] pattern recognition where there exists well defined training data, and it appears that we are able to leverage the same technology, albeit in a different manner, to [illegible] user behavior as well. There are, however, a number of challenges such as dealing with temporal based progressive training, because training data is not predefined; the network is trained as we go. An advantage of using an ANN is that we are able to provide predictions for situations that have not been seen yet.

Future interface should track a user's behavior while he or she interacts with their interface, and induces the training of a neural network. Knowledge acquired by the neural network is used to predict the user's action/navigation behavior. This allows for a dynamic [illegible] not encumbered by rigid, predefined business rules.User issues and requirements

Security, privacy and safety are the major concerns to users. People are also concerned about reliability, long-term durability and the time it might take for a long-term investment such as a smart home to repay itself.

Consistency and predictability are also important factors for ensuring smart home owners feel secure and relaxed. Users should be able to anticipate the actions and functions of their homes so that they feel comfortable with the various events and activities taking place around them. If consistency is lost, this can lead to users becoming frustrated and confused, as the application or device is not doing what the users are used to expect.Integration issues of smart homes in the smart grid

The new role of ICT as a more direct enabler of a sustainable development gives rise to a number of important challenges. These include questions such as how the ICT can contribute to energy efficiency in a community [14], how contribute to the optimal use of renewable energy, how to control a changing network topology with a huge number of energy providers, how to help to establish new energy services and solutions, or how ICT can best contribute to smart energy market places.

While even in households (which are typically complex and individualized environments) "smart" ICT can often act in the background and conserve energy by optimizing and automating some processes, further energy savings in such environments require – at least to some extent – the involvement of the consumer. This is a challenge, since human interaction is typically regarded as a loss of comfort, and saving energy is often [illegible] as a key objective but as a necessary constraint. Nevertheless, providing feedback to consumers about the energy consumption of their various activities and appliances should motivate them to change their habits and thus to contribute to the conservation of energy [15].

For the IT sector, the smart grid is being highlighted as one of the big opportunities [illegible] using IT in addressing climate change and subverting IT's historically dominantly negative impacts on energy consumption in, [illegible] households [16]. Current development of smart (micro)grids with substantial amount of distributed generation [illegible] from a focus on discrete 'technology'. Ongoing problem with deployment of renewable energy have shown that implementation is largely determined by broad social acceptance issues [illegible].

The present situation is characterized by great uncertainty regarding the future direction of the development of infrastructure, services and applications.

Households are often conceptualized as smart homes in the smart grid, and different visions about the future role of households in the smart grid are part of the discussion.

Increasing electricity demand requires either a traditional expansion of the electricity grid or investment in building a smart grid.

The smart grid solution with demand management differs from the present situation in which consumers are 'passive' or undynamic end-receivers of electricity, and where the load is adjusted according to their consumption practices and patterns. A smart grid is thus presented as both a more efficient and inexpensive solution to the challenges.

Implementing the smart grid vision is a complicated task that requires close cooperation and coordination between the different private and public actors and stakeholders. The smart grid vision still faces huge challenges in developing the ICT that can create dynamic interaction between the electricity system and consumers through monitoring, measurement, control and automation in the grid and at end-users, not to mention creation of new markets and institutional structures [18].

One of the core issues among the stakeholders with regard to the role of households in the smart grid is the question of who should manage consumption in order to provide flexibility – the consumers themselves, or the electric companies. At each end of a continuum, the core idea is that households either move their electricity consumption themselves, based on a two-way communication using for instance a smart meter and economic incentives such as real-time pricing, or they allow electric companies to manage their electricity consumption and household devices from a distance based on certain criteria.

Central to this division is whether the smart grid technologies should take part in visualizing energy consumption or in making it invisible – should people be expected to change practices, or should they 'feel' as little as possible and continue everyday life as usual?

To realize optimized control strategies that allow maximizing energy efficiency and user comfort simultaneously and

automatically, methods from AI need to be employed. An excellent means are multi-agent systems that inherently support distributed intelligence and collaboration to act towards defined goals. Different agents are brought together by an agent based framework that also embeds the intelligent control strategies. Moreover, it caters for an interfacing with the knowledge base as well as the underlying home automation systems. The system should be inhabited by a number of specialized agents that are responsible of solving different problem aspects. This distributed problem solving introduces a considerable degree of agent autonomy in the system, but also requires that communication and data exchange among the agents must be supported. This is possible to accomplish using agent based frameworks. Within this framework, the AI based intelligent control strategies should be embedded. They realize the sustainable operation by constantly striving to perform an optimal mapping between the current smart home state, the given user goals and energy efficiency [19].

The combined ontology-based MAS approach is especially beneficial considering the encountered complexity of the involved disciplines: Home automation, knowledge representation and processing, AI and context awareness have to be coupled in an intelligent fashion. The agent based approach features cooperative problem solving in which some or all agents may take part. Moreover it provides means to encapsulate software parts that can be maintained or exchanged independently and easily. This and the required communication infrastructure are very well modeled by the agent paradigm, while all knowledge on the agents' ecosystem is grounded in the knowledge base implemented as ontology. Still, a comprehensive system can only be realized if a seamless integration of the intelligent MAS and the knowledge base is pursued. This calls for a thorough system specification. Additionally, considera[illegible] effort will be devoted to the exact definition of all interfaces in [illegible] system.

A smart home should offer something for all, either in the form o[illegible] adaption or modularity, as the greatest advantages c[illegible]hieved by customizing the system to its users.

5. Conclusions

The smart home consists of a lar[illegible]nd wide ra[illegible]g set of many services, applications, equipm[illegible]orks and sy[illegible]s that act together in delivering the "inte[illegible]gent" [illegible]onnected" home in order to maintain security a[illegible]ontrol, co[illegible]ications, leisure and comfort, energy effic[illegible]y, environmenta[illegible]tegration and accessibility. These com[illegible]ents a[illegible]epresented by many actors that interact and work t[illegible]her [illegible]provide interactive systems that benefit the home based u[illegible] the sm[illegible]house. Because of this wide ranging va[illegible] of t[illegible]titi[illegible]n the smart house, there is a very high [illegible]el o[illegible]tential [illegible]exity in finding the optimal solution f[illegible]ch diff[illegible]nt smart house.

We nee[illegible]in[illegible]nt based smart home infrastructure. With tho[illegible] of objects capable of and willing to cooperate, it will be imposs[illegible]to stick to the traditional approaches, especially considering th[illegible]e-effects such as the unnecessary network utilization. Therefore investment should be done towards a publish/subscribe model, where the necessary entities can subscribe and get only the events interesting for them.

Timely monitoring and control support should also be available. Providing information exactly when it is needed, will be of key importance for business decisions.

The main focus of smart objects is in coupling the physical and virtual worlds; they do this via monitoring and control activities.

Due to high growth of Nanotechnology, Communication and networking, Simulation and modeling, Decision support and Enterprise Resource Planning, Integration, etc., it is expected that a new breed of appliances, innovative services and business applications that we can not anticipate today, will be possible.

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